



UNIVERSITI PUTRA MALAYSIA

**PHOSPHORUS IN ACID SOILS AMENDED WITH ORGANIC AND
INORGANIC INPUTS: ITS STATUS AND INTERACTIONS**

ABDUL RAHMAN BAH

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**PHOSPHORUS IN ACID SOILS AMENDED WITH ORGANIC AND
INORGANIC INPUTS: ITS STATUS AND INTERACTIONS**

By

ABDUL RAHMAN BAH

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of
Philosophy**

March 2002

DEDICATION

This work is dedicated to my parents:

ALPHA AMADU JAWOH BAH and NENEH UMU HAWA BAH

Abstract of the thesis presented to the Senate of the Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

PHOSPHORUS IN ACID SOILS AMENDED WITH ORGANIC AND INORGANIC INPUTS: ITS STATUS AND INTERACTIONS

By
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March 2002

Chairperson: Professor Dr. Zaharah Abdul Rahman

Faculty: Agriculture

The combined use of green manures (GMs) and phosphate rocks (PRs) could be a more efficient and sustainable approach in alleviating P deficiency in acid tropical soils. Understanding the chemical and biological processes or interactions influencing P dynamics in such systems is therefore, vital for adaptation to different cropping systems.

The effect of GMs and P fertilizers on two acid soils (Bungor and Selangor series) was investigated in a laboratory incubation study and two glasshouse experiments using conventional and radioisotope techniques. The treatments were a factorial combination of GMs (legumes - *Calopogonium caeruleum*, *Gliricidia sepium*, and a non-legume *Imperata cylindrica*) and P fertilizers (PRs from North Carolina, China and Algeria, and triple superphosphate), completely randomized with up to 4 replications. Olsen P, biomass P, exchangeable Ca, mineral N and acidity were monitored in the soils for 16 months, and P in the soil fractions/pools was quantified at the end of the

incubation. The relative contribution of the sources to P uptake and utilization by *Setaria* grass (*Setaria sphacelota*) was determined by the ^{33}P - ^{32}P double isotope labeling and ^{32}P isotope dilution techniques.

The P fertilizers had little effect on available P, whilst the sole GMs and GM+P amendments altered it in two phases. An initial lag phase with depressed P levels in the first 16 weeks coincided with the buildup of $\text{NH}_4\text{-N}$ (up to 1000 mg N kg^{-1}) and exchangeable Ca, elevated soil pH (up to 2.3 units), up to 5-fold increase in microbial P, and significant GM \times P \times Soil interactions. The second phase showed higher available P, and much lower $\text{NH}_4\text{-N}$, biomass P, pH. The GMs also reduced sorption capacity (by over 84%), increased available P 6-10 times, and also the Al-P and Fe-P fractions. They decreased P in the unavailable pool, the organic-P fraction and 50-75% of Ca-P in PR-amended soils. The GM contribution to P uptake was small (<5%) and the utilization was < 1%, but they caused much higher total P uptake than the P fertilizers alone (more than 160%). They improved fertilizer-P utilization from < 20% to > 50%. They significantly enhanced soil P contribution in the following order: *Gliricidia*<*Imperata*<*Calopogonium*. Unexpectedly, the low quality *Imperata* GM also increased P availability and uptake when integrated with reactive PRs, probably by improving soil moisture content. Calcium concentration, GM quality, microbial turnover, and soil P mobilizing capacity regulated P dynamics in these systems.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

FOSFORUS DALAM TANAH ASID DIRAWAT DENGAN BAHAN ORGANIK DAN TAK ORGANIK: STATUS DAN INTERAKSI

Oleh
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Mencampuran bahan organik (BO) dan batuan fosfat (BF) ke dalam tanah boleh menjadi satu cara berkesan dan mampan untuk memperbaiki kekurangan P dalam tanah-tanah asid di kawasan tropika. Fahaman terhadap proses-proses kimia dan biologi dan interaksi diantara kedua-duanya terhadap dinamik P dalam sistem tersebut adalah perlu sebelum kaedah ini boleh diadaptasikan didalam pelbagai sistem tanaman.

Kitaran P dalam dua tanah asid (Siri Bungor dan Siri Selangor) yang dirawat dengan BO dan BF telah dikaji di dalam satu eksperimen makmal dan dua eksperimen rumakaca menggunakan kaedah-kaedah konvensional dan radioisotop. Rawatan digunakan ialah kombinasi faktorial BO (kekacang – *Calopogonium caeruleum*, *Gliricidia sepium*, dan satu bukan kekacang *Imperata cylindrica*) dan baja-baja P (BF dari North Carolina, Cina dan Algeria, dan baja superfosfat tripel), yang diatur secara rawak lengkap dengan 4 replikasi. P-Olsen, biomasa-P, Ca tukarganti, N mineral dan keasidan tanah telah diukur selama 16 bulan. Diakhir masa pemeraman ini, pecahan P dalam tanah di

tentukan. Sumbangan relatif punca baja P terhadap P diserap dan digunakan oleh rumput Setarai (*Setaria sphacelata*) ditentukan dengan kaedah-kaedah penglabelan dwi-isotop ^{32}P - ^{33}P , dan pencairan isotop ^{32}P .

Sumber baja P yang digunakan tidak menunjukkan kesan ketara terhadap P kedapatan, manakala BO dan BO+P mengubah P kedapatan dalam dua fasa. Fasa permulaan menunjukkan tahap P yang menurun pada 16 minggu pertama, di mana fasa ini juga menunjukkan peningkatan $\text{NH}_4\text{-N}$ (sehingga 1000 mg N kg^{-1}) dan Ca tukarganti, pH tanah meningkat (sehingga 2.3 unit), peningkatan sehingga 5 kali ganda, biomasa P dan interaksi yang ketara diantara $\text{BO} \times \text{P} \times \text{tanah}$. Fasa kedua menunjukkan peningkatan kedapatan, dan P tanah, $\text{NH}_4\text{-N}$, biomassa P dan pH yang menurun. Bahan organik juga didapati menurunkan keupayaan pengikatan P ($> 84\%$), meningkatkan P kedapatan 6-10 kali ganda, dan juga pecahan-pecahan Al-P dan Fe-P. Bahan organik juga boleh mengurangkan P tidak kedapatan, pecahan P organik dan 50-75% daripada pecahan Ca-P dalam tanah yang di rawat dengan BF. Sumbangan bahan organik terhadap P kedapatan adalah kecil ($< 5\%$) dan keberkesanannya ialah $< 1\%$ tetapi, ia dapat meningkatkan jumlah P yang diserap dibandingkan dengan baja P sahaja ($> 160\%$). Ia dapat meningkatkan keberkesanan P dari $< 20\%$ to $> 50\%$, dan meningkatkan dengan ketara sumbangan P tanah mengikut turutan *Gliricidia* $<$ *Imperata* $<$ *Calopogonium*. *Imperata*, sebagai bahan organik berkualiti rendah, telah dapat meningkat P kedapatan dan P diserap apabila dicampurkan dengan BF reaktif, berkemungkinan kesan daripada peningkatan

kelembapan tanah. Kepekatan Ca, kualiti BO, kitarsemula mikrob dan keupayaan pergerakan P dalam tanah adalah faktor-faktor yang mengawal dinamik P dalam sistem ini.

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I certify that an Examination Committee met on 30th March 2002 to conduct the final examination of Abdul Rahman Bah on his Doctor of Philosophy thesis entitled "Phosphorus in Acid Soils Amended with Organic and Inorganic Inputs: Its Status and Interactions" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



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TABLE OF CONTENTS

	Page
DEDICATION	2
ABSTRACT	3
ABSTRAK	5
ACKNOWLEDGEMENTS	8
APPROVAL	10
DECLARATION	12
LIST OF TABLES	17
LIST OF FIGURES	20
 CHAPTER	
I INTRODUCTION	22
II LITERATURE REVIEW	28
Importance of Phosphorus	28
Forms of Soil P	29
Fractions of Inorganic P	29
Organic P	31
Inositol Phosphates	33
Phospholipids	34
Nucleic Acids	34
Important Reactions of P in soils	35
Precipitation Reactions	35
Sorption reactions	37
Transformation of organic P	39
Phosphate Rock as a Source of P	41
Methods of Increasing PR Reactivity	45
Effect of Organic Amendments on P Availability	47
Important Measurements in P Dynamics	50
The Potential of GM-PR Mixtures in the Tropics	56

III	GENERAL METHODOLOGY	58
	Materials and Methods	59
	Materials.....	59
	Methods	59
	Characterization of Experimental Materials	60
IV	THE DYNAMICS OF P AVAILABILITY IN ACID SOILS AMENDED WITH GREEN MANURES AND PHOSPHATE ROCKS	65
	Introduction.....	65
	Method	68
	Incubation Procedure	68
	Chemical Analysis	68
	Data Analysis	69
	Results.....	70
	Mineral N Accumulation and Changes in Soil pH	70
	Changes in Bicarbonate Extractable P during Incubation.....	83
	Changes in Chloroform extractable P	87
	Changes in Exchangeable Ca	95
	Discussion	101
	Conclusions.....	108
V	THE DISTRIBUTION AND BIOAVAILABILITY OF P IN ACID SOILS AMENDED WITH PHOSPHATE ROCKS AND GREEN MANURES	110
	Introduction.....	110
	Methods.....	113
	Soil P Fractions	113
	Phosphate Sorption Studies	114
	Isotope Exchange Kinetics	115
	Data Analysis	115
	Results	118
	Soil P Fractions	118
	P Sorption Studies.....	126
	Equilibrium P Concentration.....	126
	Affinity Constants.....	127

	P Sorption Maxima	127
	³² P Isotope Exchange Kinetic Studies	129
	Treatment Effect on some Exchangeable Cations	138
	Discussion	140
	Conventional Methods of Evaluating P Status.....	141
	Soil P Status Evaluated by ³² P Isotope Techniques	146
	Conclusions.....	148
VI	NUTRIENT AVAILABILITY AND UPTAKE BY SETARIA GRASS (Setaria sphacelata) GROWN IN ACID SOILS AMENDED WITH GREEN MANURES AND P FERTILIZERS	150
	Introduction.....	150
	Methods.....	152
	Experimental procedure	152
	Data analysis.....	153
	Results	154
	Dry matter production.....	154
	Phosphorus uptake by Setaria grass.....	156
	Phosphorus derived from treatments.....	158
	Effect of treatments on calcium uptake by Setaria grass.....	161
	Discussion	163
	Conclusions.....	172
VII	THE RELATIVE CONTRIBUTION OF GREEN MANURES AND PHOSPHATE ROCKS TO P AVAILABILITY AND UPTAKE IN AMENDED ACID SOILS	174
	Introduction.....	174
	Materials and Methods	177
	Methods.....	177
	Labeling the GMs	177
	Growth of Setaria Grass	177
	Data Analysis	178
	Results	180
	Dry Matter Yield of Setaria Grass.....	180

Total P Uptake.....	181
Contribution of Organic and Inorganic Sources to P Uptake	187
Utilization of P from the Amendments	196
Discussion.....	202
Conclusion.....	208
VIII SUMMARY AND CONCLUSIONS.....	210
REFERENCES.....	221
BIODATA OF THE AUTHOR	238

LIST OF TABLES

Table		Page
3.1	Chemical characteristics of the green manures used.....	62
3.2	Some chemical properties of the P fertilizers used.....	63
3.3	Some characteristics of soils used in the experiments.....	64
4.1	Correlations between pH and some soil properties monitored during incubation of acid soils amended with GMs alone or in combination with inorganic P fertilizers.....	73
4.2	Analysis of variance showing the effect of GMs, P fertilizers and soil type on soil properties monitored during the 64-week incubation of amended acid soils.....	78
4.3a	Differences between the integrated GM-P amendments and the corresponding sole treatments in some soil chemical properties of acid soils after 4 weeks of incubation.....	80
4.3b	Differences between the integrated GM-P amendments and the corresponding sole treatments in some soil chemical properties of acid soils after 8 weeks of incubation.....	81
4.3c	Differences between the integrated GM-P amendments and the corresponding sole treatments in some soil chemical properties of acid soils after 16 weeks of incubation.....	82
4.4	Correlation between P_{chl} and available P during incubation of acid soils amended with green manures alone and in combination with P fertilizers.....	105
4.5	Influence of some GM chemical characteristics on P_{chl} in amended acid soils.....	107
5.1	Soil P fractions ($\mu\text{g g}^{-1}$ soil) after 64 weeks of incubation of Bungor and Selangor soils that were amended with inorganic P fertilizers and green manures.....	119
5.2	Soil P fractions ($\mu\text{g g}^{-1}$ soil) after 64 weeks of incubation of Bungor and Selangor soils that were amended with mixtures of inorganic P fertilizers and green manures.....	121

5.3	Correlations between soil P fractions and available P ^a in acid soils amended with green manures and P fertilizers at the end of a 64-week incubation.....	124
5.4	Stepwise multiple regressions between soil P fractions and available P ^a after a 64-week incubation of acid soils treated with green manures and P fertilizers.....	125
5.5	Equilibrium P concentrations (10 ⁻³ mmol P L ⁻¹) in acid soils amended with GMs and P fertilizers after a 64-week incubation..	126
5.6	Affinity constants (Lmol ⁻¹) of acid soils amended with GMs and P fertilizers after a 64-week incubation.....	127
5.7	Langmuir P sorption maxima (cmolPkg ⁻¹) of acid soils amended with GMs and P fertilizers after a 64-week incubation.....	128
5.8	Changes in kinetic parameters and pools of bioavailable P in acid soils amended with GMs and P fertilizers after 64 weeks of incubation.....	130
5.9	Changes in kinetic parameters and pools of bioavailable P in acid soils amended with a combination of GMs and P fertilizers after 64 weeks of incubation.....	133
5.10	Exchangeable cations in acid soils amended with GMs and P fertilizers after a 64-week incubation.....	139
6.1	Dry matter production of Setaria grass grown in acid soils amended with GMs and P fertilizers.....	154
6.2	Total P taken up by Setaria grass grown in acid soils amended with GMs and P fertilizers.....	157
6.3	The P in Setaria derived from the treatments in acid soils amended with GMs and P fertilizers.....	159
6.4	Total Ca taken up by Setaria grass grown in acid soils amended with GMs and P fertilizers.....	162
6.5a	Treatment effects on bioavailable soil P parameters and the pool sizes in a Bungor soil at 8 WAT.....	164
6.5b	Treatment effects on bioavailable soil P parameters and the pool sizes in an acid sulphate soil (Selangor) at 8 WAT.....	165

6.6	Nutrients added by the GM amendments.....	167
6.7	Soil moisture content of acid soils incubated with Imperata and P fertilizers.....	169
6.8	Soil microbial P in acid soils amended with GMs and P fertilizers at 8 WAT.....	170
7.1	Cumulative dry matter production by Setaria grass grown in acid soils amended with GMs and P fertilizers after 20 weeks....	181
7.2	Cumulative Phosphorus yield in Setaria grass after 4 harvests in acid soils amended with GMs and P fertilizers.....	187
7.3	Phosphorus utilization from GMs by Setaria grass grown in acid soils amended with green manures and P fertilizers after 4 harvests.....	196
7.4	Phosphorus utilization from P fertilizers by Setaria grass in acid soils amended with GMs and inorganic P fertilizers.....	198
7.5	Estimates of P recovered in Setaria by isotopic and conventional methods.....	200
7.6	Quantity of nutrients added by the applied green manures.....	204

LIST OF FIGURES

Figure		Page
4.1	Variation of soil mineral N during incubation of acid soils amended with green manures.....	71
4.2	Variation of pH during incubation of two acid soils amended with green manures.....	72
4.3	Variation of pH during incubation of two acid soils (B = Bungor; S = Selangor) amended with mixtures of CPR and APR with green manures.....	74
4.4	Variation of soil mineral N during incubation of acid soils (B=Bungor, S = Selangor) amended with green manures and China phosphate rock (CPR).....	75
4.5	Variation of soil mineral N during incubation of acid soils (B = Bungor, S = Selangor) amended with green manures and Algerian phosphate rock (APR).....	76
4.6	Variation of available P during the incubation of acid soils (B = Bungor; S = Selangor) amended with phosphate rocks and green manures. Control.....	84
4.7	Variation of available P during the incubation of acid soils (B = Bungor; S = Selangor) amended with mixtures of green manures and phosphate rocks.....	86
4.8	Variation of chloroform extractable P during incubation of acid soils (B = Bungor; S = Selangor) amended with P fertilizers and green manures.....	88
4.9	Variation of chloroform extractable P during incubation of acid soils (B = Bungor; S = Selangor) amended with mixtures of green manures and phosphate rocks.....	92
4.10	Variation of exchangeable Ca during incubation of acid soils (B = Bungor; S = Selangor) amended with P fertilizers and green manures.....	96
4.11	Variation of exchangeable Ca during incubation of acid soils (B = Bungor; S = Selangor) amended with mixtures of green manures with CPR and APR.....	99

7.1	Phosphorus uptake by Setaria grass grown in acid soils (B = Bungor; S = Selangor amended with P fertilizers and green manures.	182
7.2	Phosphorus uptake by Setaria grass grown in acid soils (B = Bungor; S = Selangor amended with mixtures of P fertilizers and green manures.....	184
7.3	Percent contribution of P fertilizers and GMs to P uptake by Setaria grass grown in amended acid soils.....	188
7.4	Effect of GMs on %P derived from APR and CPR by Setaria grass grown in amended acid soils (B = Bungor soil and S = Selangor soil).....	190
7.5	Effect of GMs on cumulative P uptake from APR by Setaria grass grown in amended acid soils (B = Bungor soil and S = Selangor soil).....	191
7.6	Cumulative P uptake from GMs by Setaria grass grown in amended acid soils (B = Bungor and S = Selangor).....	192
7.7	Soil contribution to P uptake by Setaria grass grown in GM-amended acid soils (B = Bungor and S = Selangor).....	194
7.8	Soil contribution to P uptake by Setaria grass grown in acid soils (B = Bungor; S= Selangor) amended with mixtures of GMs and phosphate rocks	195
8.1	The schematic representation of chemical and biological interactions in soils amended with legume GMs and PRs.	215

CHAPTER I

INTRODUCTION

Phosphorus deficiency is a major factor limiting crop production in tropical areas due to the prevalence of highly weathered Ultisols and Oxisols, which make up about 43% of the land area (Sanchez and Uehara, 1980; Sanchez and Logan, 1992). These soils have low base saturation, toxic levels of Al and are generally low in nutrient reserves, especially of N and P (Sanchez and Uehara, 1980). Additionally, they can fix large quantities of applied P due to the high proportion of sesquioxides, the dominance of 1:1 clays and their medium-to-fine texture (Juo and Fox, 1977; Schwertmann and Herbillon, 1992; Frossard et al., 1995). Phosphorus is required for the efficient uptake and utilization of N, and it is also vital for many plant metabolic processes (Brady and Weil, 1999). This implies that deficiency in this nutrient can severely disrupt normal plant growth and reproduction, which eventually translates to drastic reduction in crop yields. Therefore, increasing crop productivity in the tropics is mostly dependent on how efficiently P is managed in agro-ecosystems.

Currently, traditional farming systems in the tropics have a much shorter fallow component because of greater demographic pressure. As fertilizer usage in these systems is quite uncommon, intensive cultivation activities often lead to deterioration in soil fertility, and ultimately land degradation. Moreover,

inadequate P nutrition also results in sparse vegetation cover during the short fallow periods. This exposes the soil to the direct impact of the heavy rains common in tropical areas, and hence to greater loss of the topsoil by erosion. This subsequently results in serious pollution problems, which can jeopardize drinking water, endanger aquatic life and even affect the operation of dams and irrigation facilities. The problem becomes more widespread and severe as additional marginal lands are brought under cultivation and the cycle of degradation is repeated.

Recent strategies proposed to mitigate P deficiency include a large one-time fertilizer gift to replenish soil P, followed by regular maintenance applications for a few seasons (Buresh et al., 1997; Sanchez et al., 1997). The massive P application is designed to permanently saturate the sorption sites and provide P for crop uptake. The stock that provides P over a period of 5-10 years is referred to as 'soil P capital' whilst the P available during an annual cropping cycle is called 'liquid P' (Sanchez et al., 1996; Buresh et al., 1997). However in most cases, the use of soluble P fertilizers in the management of soil fertility in the tropics has proved to be uneconomical, mainly due to the costs involved and the low utilization efficiencies emanating from high P fixation (Juo and Fox, 1977; Iyamuremye and Dick, 1996). In addition, there are enormous distribution problems involved because of poor infrastructure, and sometimes, complete unavailability of these fertilizers. Furthermore, the dire economic circumstances of people in these areas make the cost of high analysis fertilizers prohibitive for

most farmers. This is exacerbated by depressed commodity prices and the current policy of eliminating fertilizer subsidies by governments. Other important factors include the deleterious environmental effects associated with the use of these materials, especially under the high rainfall conditions common in this climatic zone.

The direct application of phosphate rocks (PRs) has shown great promise as a cheap and environmentally benign source of P in acid soils (Chien et al., 1980; Rajan et al., 1996). However, in many cases the effectiveness of these materials is very much restricted by their low reactivity. Therefore, various techniques have been used to improve their efficiency. The most attractive among these are the ones incorporating organic materials, for instance composting PRs with organic materials is reported to improve their effectiveness tremendously (Ikerra et al., 1994; Yang et al., 1994). In the same way, green manures (GMs) have been observed to increase the action of less reactive PRs (Zaharah and Bah, 1997). The extent of this effect was very much dependent on the biochemical characteristics of the GMs, especially the C-to-P ratio. Organic ligands and acids released during GM decomposition (Swift et al., 1979) are thought to play a key role in improving the solubility of the PRs (Chien, 1979). However, more information is required to fully understand the magnitude and duration of the influence of nutrient interactions on P release from the PRs, and its overall availability in the soil-GM-PR system. In general, integrating P fertilizers with high quality organic inputs is known to improve their efficiency by